VA | U.S. Department of Veterans Affairs

Auditory Effects of Blast-Exposure in Service Members and Veterans

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HSRD Cyberseminar
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BACKGROUND: COMMUNICATION IS CRITICAL

The ability to hear is critical to success on the battlefield and in daily life

2007-present DoD and VA Audiology Clinics reporting cases of Service Members with.....

- One or more blast exposures (roughly 80% of all casualties) 1-4
- Could have traumatic brain injury (TBI), 90% mild ("signature" wound, approximately 400,000 confirmed cases from 2000-2018) [1]
- Clinically normal to near-normal hearing thresholds [2-4]
- Report difficulty understanding speech in complex settings [1]

[1] Gallun et al. (2012) JRRD, Saunders et al. (2015) JRRD, Tepe et al (2020) acquired APD
[2] Saunders et al. (2015) JRRD: 99 of 99 (100%) blast-exposed
[3] Lew et al. (2007a) JRRD: 16 of 42 (38%) blast-related TBI subjects
[4] Lew (2007b) JRRD: 65% of VA Polytrauma Care patients

BACKGROUND: COMMUNICATION IS CRITICAL

- Complaints from Service Members returning from combat include:
  - Listening in reverberant multi-talker environments or when speaker is talking fast
  - Following long conversations
  - Localizing sounds
  - Tinnitus
  - Sound sensitivity (hyperacusis)
  - Other non-auditory sensory issues (e.g., photophobia)
  - Dizziness

BACKGROUND: EVIDENCE OF ABNORMAL PERFORMANCE

STUDY 1

NCRAR/WRAMC`

(VA Funded)

44% of Blast-exposed Service Members (SMs) abnormal on CAPD measures

Binaural processing

Speech in Noise

Binaural integration

Behavioral & Evoked Potentials

Gallun et al. 2012

STUDY 2

WRNMMC

(DMRDP/APHC Funded)

30% of Blast-exposed SMs abnormal on functional measures

Modified Speech, Spatial, and Qualities of Hearing

Binaural Integration

Speech in Noise

Binaural Processing (Quick SIN)

Brungart et al. 2014

STUDY 3

WRNMMC

(CDMRP/DoD)

Blast-exposed SMs were less accurate localizing sounds with competing talkers than controls

CUNY sentences

3 Conditions

Quiet

1 Competing

2 Competing

Kubli et al. 2018

CLINICAL DATA

WRNMMC

110 Patients

55% Blast-exposed

70% Abnormal on combination of tests

63% Diagnosed with APD

Binaural Integration

Binaural Processing

BACKGROUND: POSSIBLE REASONS

- Peripheral Distortion – Synaptopathy?
- Auditory Processing Disorder?
- Sensory Processing Disorder?
- Cognitive Processing Deficit?
  - Attention
  - Working memory
  - Speed of processing

Functional hearing and communication deficits (FHCD) in the presence of normal audiogram

Normal Hearing

Distorted Hearing

Speech in Noise, Babble, and Reverberation:

What about Service Members (SMs) who Do NOT Seek Clinical Services?

Question: How large of a problem is this?

- SMs are required to get annual hearing exams to monitor their hearing using pure tone thresholds (audiogram)
- Audiogram is limited in how much it can tell us about hearing health
- Estimated number of SMs with similar problem understanding speech in complex noisy environments.
- Do SMs with noise and blast exposure history (training missions and deployments) have auditory issues?

Grant, Kubli, Phatak, Galloza & Brungart (2021). Estimated Prevalence of Functional Difficulties in Blast-Exposed Service Members with Normal or Near-Normal Hearing Thresholds. *Ear & Hearing* Nov-Dec 01;42(6):1615-1626.

ESTIMATED PREVALENCE OF AUDITORY ISSUES : WALTER REED NATIONAL MILITARY MEDICAL CENTER STUDY

Phase I: "Walter Reed Prevalence Study"

Apply auditory tests and subjective survey to Service Members during annual hearing checkup

Phase II: In-depth assessment of possible causes of functional deficits in blast-exposed individuals

- Auditory processing (evoked potentials, behavioral tests, auditory working memory, etc.)
- Cognitive deficits using visual and auditory tests (attention, memory, speed of processing etc.)

Phase I: Multi-site study conducted at Defense Occupational and Environmental Health Readiness System—Hearing Conservation (DOEHRS-HC) clinics at:

- **San Antonio Military Medical Center**
- **Naval Medical Center San Diego**
- **Walter Reed National Military Medical Center**

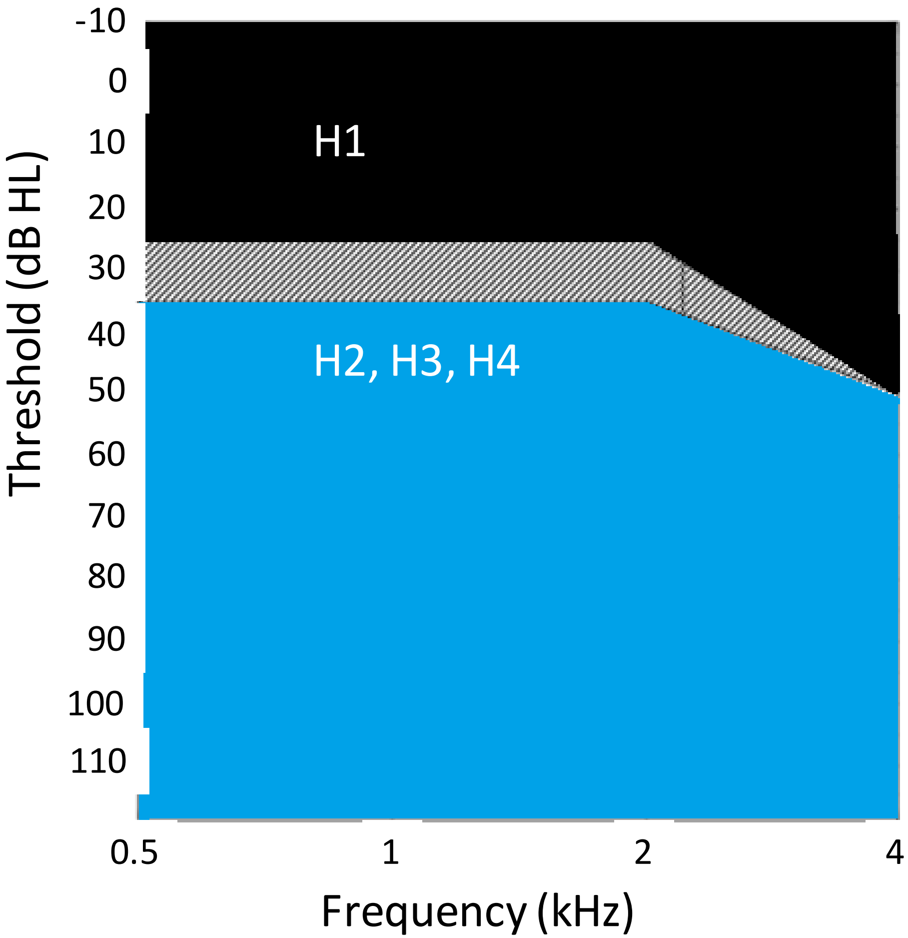
Phase I:

1. Prevalence of SMs who report blast-exposure with normal or near-normal (H1 profile) and have difficulty understanding speech in noise

2. Examine the relationship between self-perceived communication difficulty, exposure to blasts, profile status, and performance on auditory screening measure (MLD/Speech-in-Noise)

* H1 Profile: Pure-tone average not more than 25 dB HL at 500 Hz, 1000 Hz, 2000 Hz with no individual level greater than 30 dB HL; 4000 Hz not over 45 dB HL

H1 Profile (AR 40-501; Table 7-1) (shaded black region)



Some hearing loss allowed and still be profiled as H1
HI: functionally normal or "fit for duty"

PTA for each ear not more than 25 dB at .5, 1, 2 kHz with no individual level greater then 30 dB

≤ 45 dB at 4000 Hz

Grey stippled area must be resolved on a case-by-case basis

WALTER REED PREVALENCE STUDY: METHODS

1) Audiogram
2) Responses to Surveys
   - Demographic data
   - Self reported history of blast exposure
   - Subjective hearing performance from hearing survey (Modified Speech, Spatial, and Qualities of Hearing or modified SSQ)
3) Auditory Tests: Speech Reception Thresholds
   - **Two tests of binaural integration: Binaural Masking Level Difference Test (MLD):** N_0S_0 and N_0S_π conditions
   - **Two speech-in-Noise tests: Oldenburg Matrix Test (OMT)** Sentences in background noise: Standard & Reverberation with speaking rate increased

Testing conducted using Android tablets platform with custom software and headphones

- Self-Administered
- Can be done anywhere: in the clinic, in the field
- Measure of functional communication ability rather than audibility (i.e., pure-tone thresholds)
- Abbreviated Consent Form

Data from DOEHRS-HC (hearing screening, age, and sex etc.) are coded and stored in an encrypted QR code

QR code is printed on the audiogram from a scanner connected to the DOEHRS HC

QR code is scanned into the tablet before **or** after testing

Information from DOEHRS HC may be manually added before or after testing

QR Code used to simplify and protect SM information

Oldenburg Matrix Test (OMT)

Kathy gives nineteen old windows.

First	Second	Third	Fourth	Fifth
Allen	bought	two	cheap	chairs.
Doris	gives	three	dark	desks.
Kathy	got	four	green	flowers.
Lucy	has	seven	heavy	houses.
Nina	kept	eight	large	rings.
Peter	ordered	nine	old	sofas.
Rachel	prefers	twelve	pretty	spoons.
Steven	sees	fifteen	red	tables.
Thomas	sold	nineteen	small	toys.
William	wants	sixty	white	windows.

Condition 1: "OMT Standard"

- Female target talker
- Spatially separated 4 talker babble
- Normal speaking rate
- SNR: 5, 2, 1, -4, -7, -10

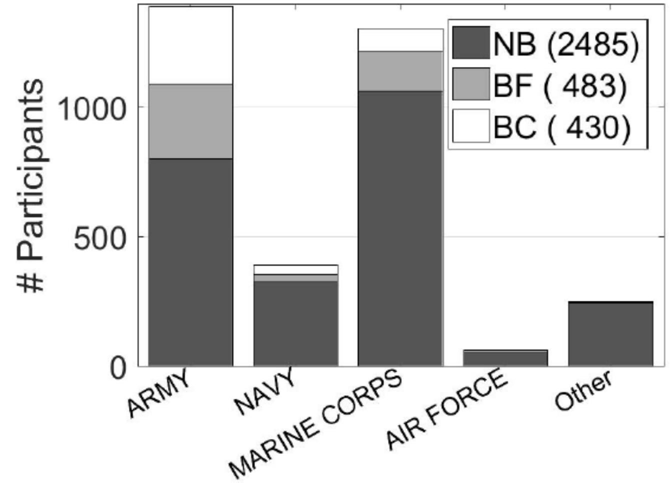
Condition 2 "OMT Speedy"

- Female target talker
- Spatially separated 4 talker babble
- Speaking rate increased by 50% (66%-time compression); reverberation RT 60 time of .25 seconds

Subjects:

3398 active duty SMs tested with normal- to near-normal hearing thresholds

- Subjects were subdivided into 6 groups
- One time deployment to Iraq or Afghanistan (various branches of the military)



3 levels of blast severity

No blast (NB)

Blast far (BF)

Blast close (BC)

2 levels of hearing thresholds

Normal-hearing thresholds (NHT, ≤ 20 dB HL)

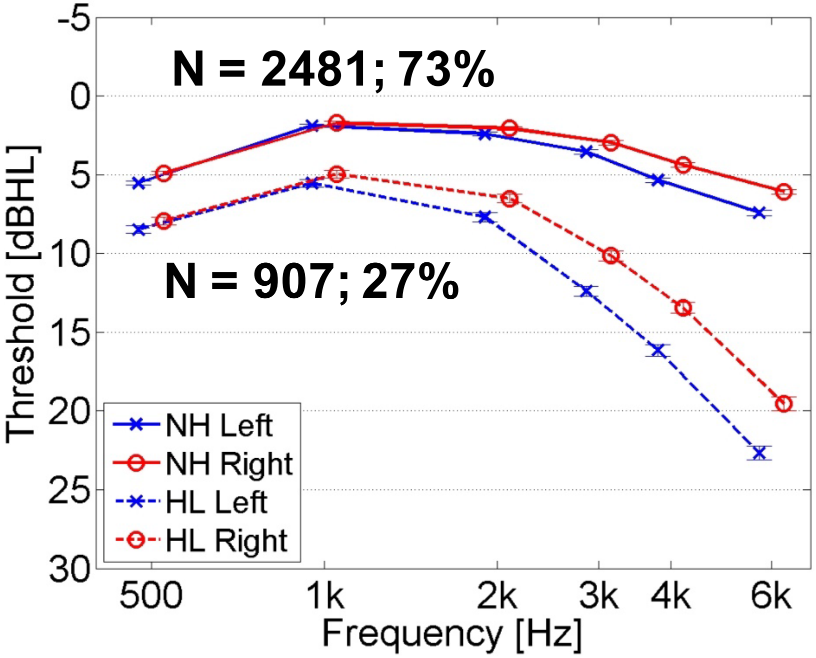
Elevated-hearing thresholds (EHT)

WALTER REED PREVALENCE STUDY: RESULTS

Table I. The number and average age of listeners in the six listener groups. The number column also lists the number of male (M) and female (F) listeners in parenthesis, and the age column lists the mean ± one standard deviation across each group. NB=no-blast, BF=blast-far, BC=blast-close, NHT=normal-hearing thresholds, and EHT=elevated-hearing thresholds.

Group	**Number (M/F)**	**Age [years]**
NB-NHT	1943 (1457/486)	26.4 ± 6.5
NB-EHT	542 (442/100)	30.3 ± 9.5
BF-NHT	313 (237/76)	34.4 ± 7.6
BF-EHT	170 (143/27)	38.2 ± 8.0
BC-NHT	235 (205/30)	35.2 ± 6.6
BC-EHT	195 (178/17)	38.2 ± 8.5

WALTER REED PREVALENCE STUDY: RESULTS



	PTA (.5, 1, 2 kHz)	PTA (3, 4, 6 kHz)
NH Left ear	3.3	5.4
NH Right ear	2.9	4.5
HL Left ear	7.2	17.1
HL Right ear	6.5	14.4

HL defined as any hearing threshold > 20 dB

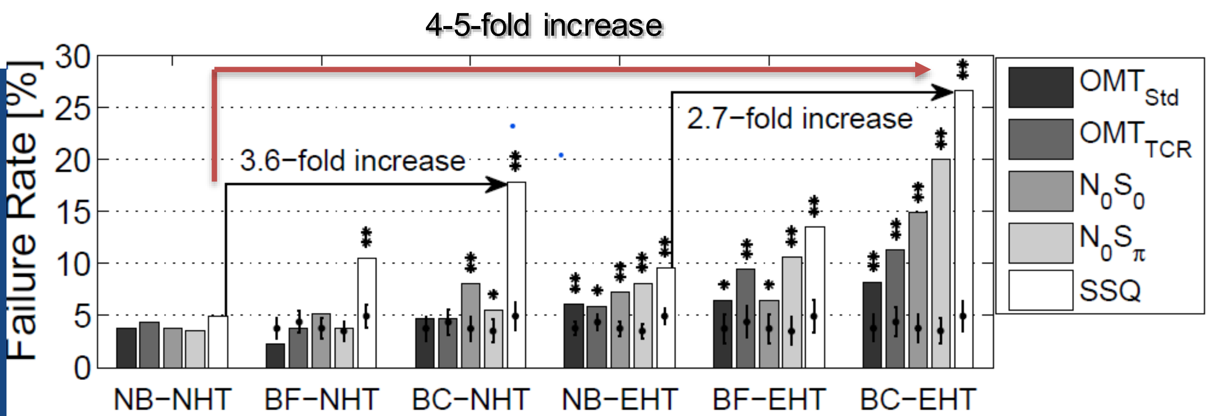
Among subjects who were blast exposed, 41% had some degree of hearing loss

- History of blast exposure connected with loss of hearing in high-frequencies

- Self-reported high levels of noise exposure consistent with HL in ultra high-frequencies

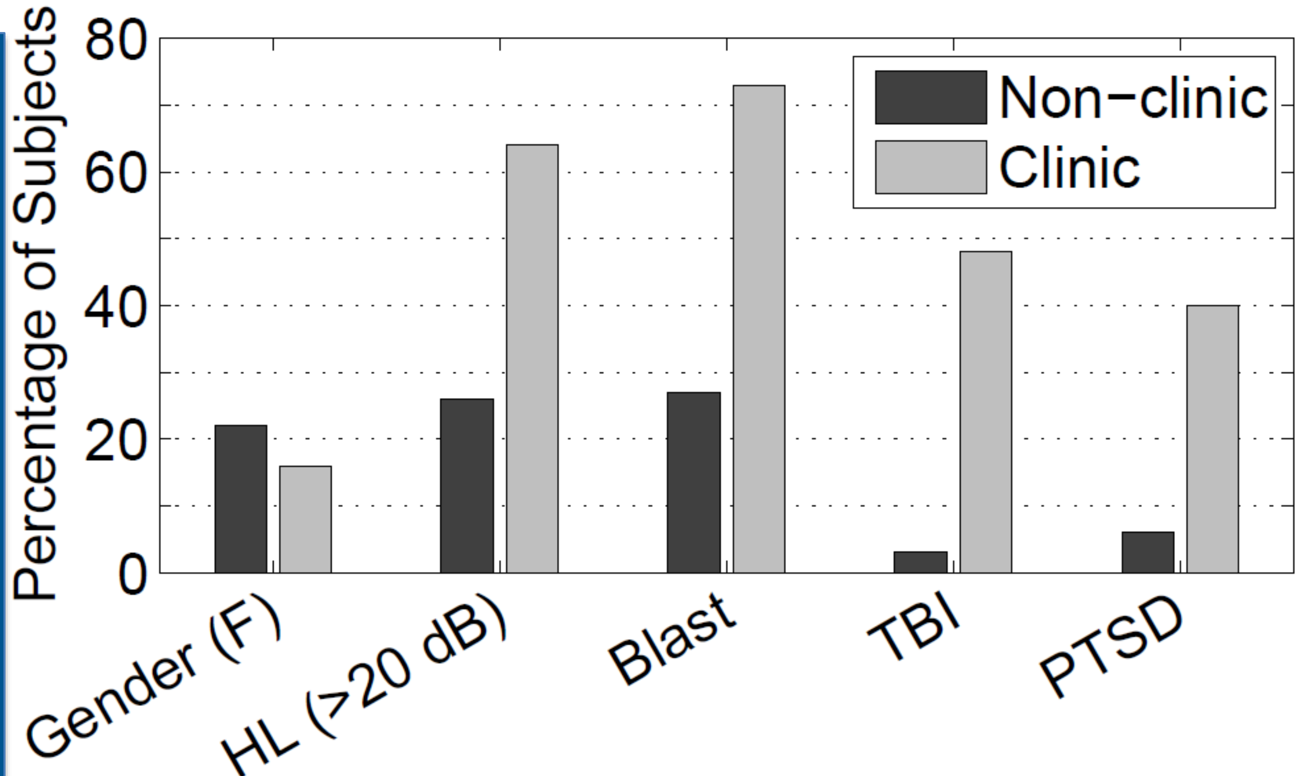
WALTER REED PREVELANCE STUDY: RESULTS

- Risk factors:
  - Blast Exposure Level (3):
    - No blast (NB)
    - Blast far (BF)
    - Blast close (BC) – felt heat or pressure
  - Hearing Thresholds (2)
    - Normal hearing thresholds (NHT) ≤ 20 dB HL
    - Elevated hearing thresholds (EHT) – at lease one hearing threshold ≥ 25 dB HL
  - Interaction Blast Exposure * Hearing thresholds



WALTER REED PREVALENCE OF FUNCTIONAL AUDITORY PROBLEMS: CONCLUSIONS

Comparison of non-clinical (Prevalence study participants) with clinical patients seen at WRMMMC (2013-2018) for further diagnostic testing using complex tasks (CAPD testing) N=200 all with H1 profiles



Clinic patients with H1 profiles N=200; Non-clinical N=3398

WALTER REED PREVALENCE OF FUNCTIONAL AUDITORY PROBLEMS: CONCLUSIONS

Pure-tone audiogram and hearing profile does not predict performance on complex communication tasks

Estimated 33.6 % blast-exposed SMs with thresholds >20 (H1) profile are at risk for auditory issues

Blast-exposed SMs (NH and HL) roughly 2-5 times as likely to perform abnormally on auditory measures than non-blast exposed SMs

HL and Blast-exposure may have a compounding effect on communication

Combination of quick tests may determine who requires further evaluation

Evaluation of communication ability requires a multi-level evaluation approach

End goal: Identify test battery and evaluate efficacy of intervention strategies

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- Brungart, D., Sheffield B., Kubli, L. (2014) Development of a test battery for evaluating speech perception in complex listening environments. *J Acoust Soc Am* August; 136(2):777-90.
- Gallun, E., Diedesch, A., Kubli, L., Walden, T., Folmer, R., Lewis, S., McDermott, D., Fausti, S. & Leek, M. (2012). Performance on tests of central auditory processing by individuals exposed to high-intensity blasts. *J. Rehabil Res Dev*. 49(7) 1005-24
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- Kubli, L., Brungart, D., Northern, J. (2018). Effect of Blast Injury on Auditory Localization in Military Service Members. *Ear & Hearing.* May-Jun; 39(3):457-469

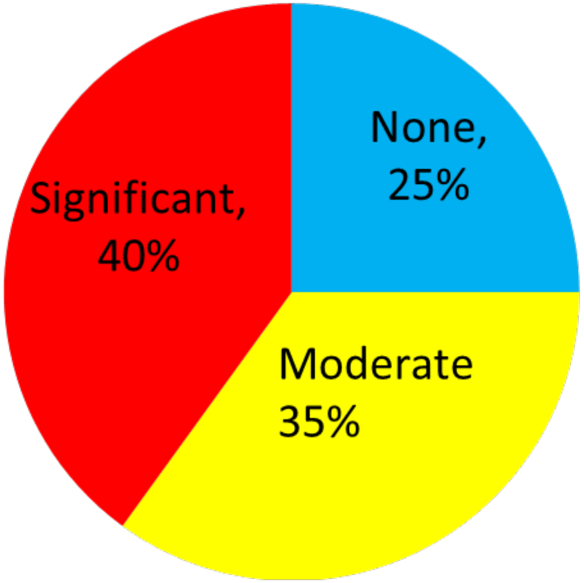
- Located at VA Portland Medical Center, Portland OR
- 18 Core Investigators
- Over 40 supporting staff members

Mission: to improve the quality of life of Veterans and others with hearing and balance problems through clinical research, technology development, and education that leads to better patient care.

- Auditory deficits are often ***chronic***
  - Gallun et al., (2016). Chronic Effects of Exposure to High-Intensity Blasts: Results of Tests of Central Auditory Processing, JRRD 53(6), 705-720.

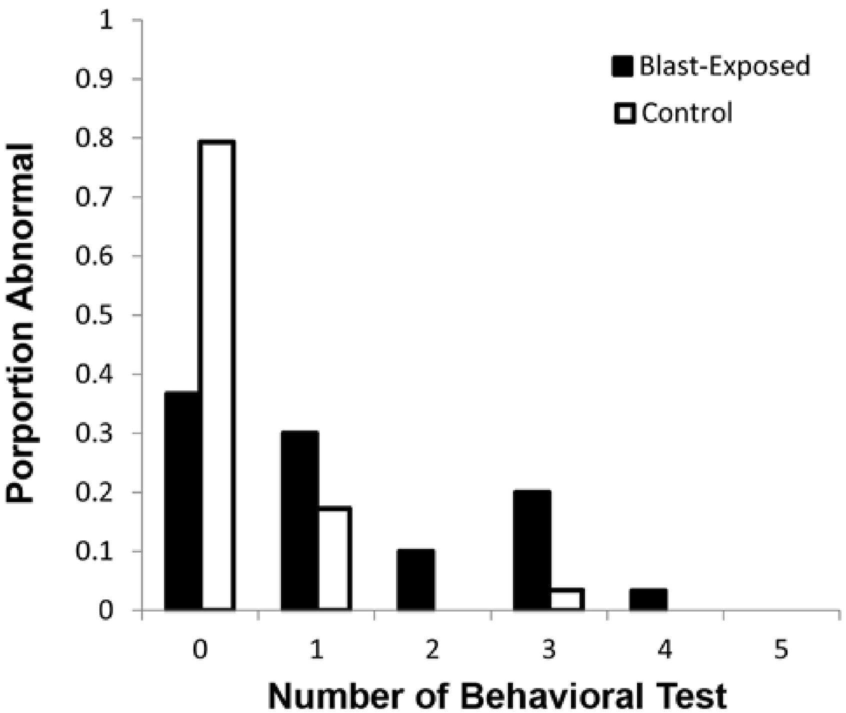
  - 30 Blast-exposed & 29 control participants, all with clinically normal or near-normal hearing sensitivity
  - Average age = 37
  - Average time since blast = 7 years
  - Blast-exposed participants reported ***significantly more hearing handicap*** compared to controls

Hearing Handicap Inventory for Adults:



- Auditory deficits are often ***chronic***
  - Gallun et al., (2016). Chronic Effects of Exposure to High-Intensity Blasts: Results of Tests of Central Auditory Processing, JRRD 53(6), 705-720.

  - 63.3% Blast-exposed failed at least one auditory processing test
    - 37% failed 2 or more tests
  - Failures on tasks such as:
    - Temporal resolution
    - Pattern recognition
    - Binaural integration
    - Dichotic listening

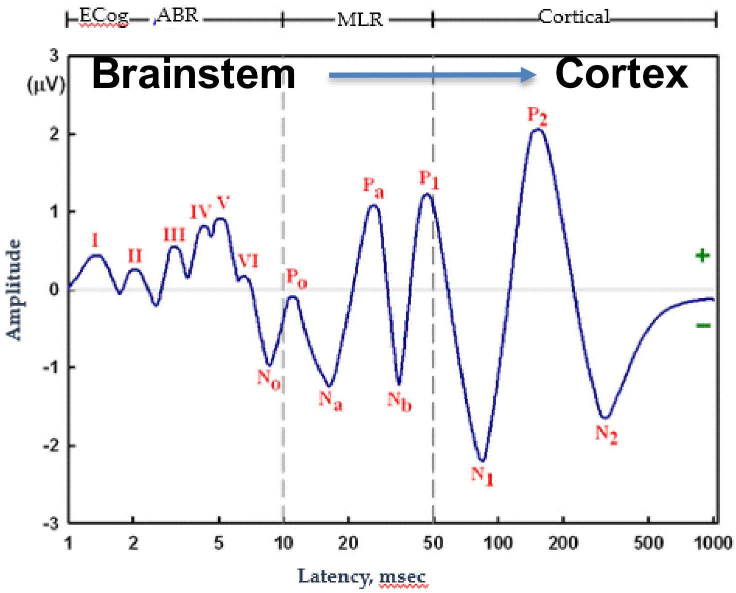


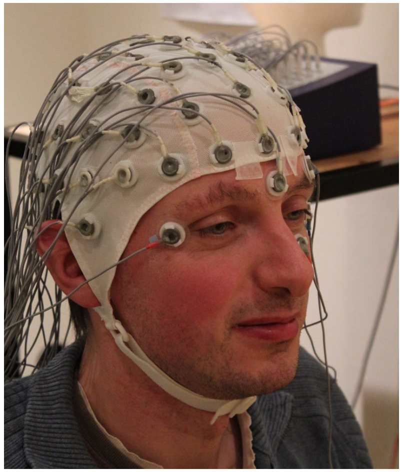
NEURAL CHANGES UNDERLYING AUDITORY DIFFICULTIES FOLLOWING BLAST EXPOSURE

- *Blast-related auditory difficulties could be related to:*
  - Damage/changes within the auditory pathway
  - Damage/changes in the brain affecting auditory and other functions
    - Other sensory pathways, post-concussive symptoms, PTSD, etc.
  - Damage/changes in cognitive pathways not specific to auditory function

Why Auditory Evoked Potentials?

- Distinguish where in the brain processing has been affected
  - Cochlea, Brainstem, Auditory Cortex, Cognitive areas
- Incredible temporal precision
- Non-invasive
- Often, no behavioral response required
  - Patients can sleep or watch movies
  - Removes cognitive/behavioral confounds
- Can be combined with behavioral response and paradigms testing cognition
- Clinical applications





AUDITORY CHANGES FOLLOWING BLAST EXPOSURE

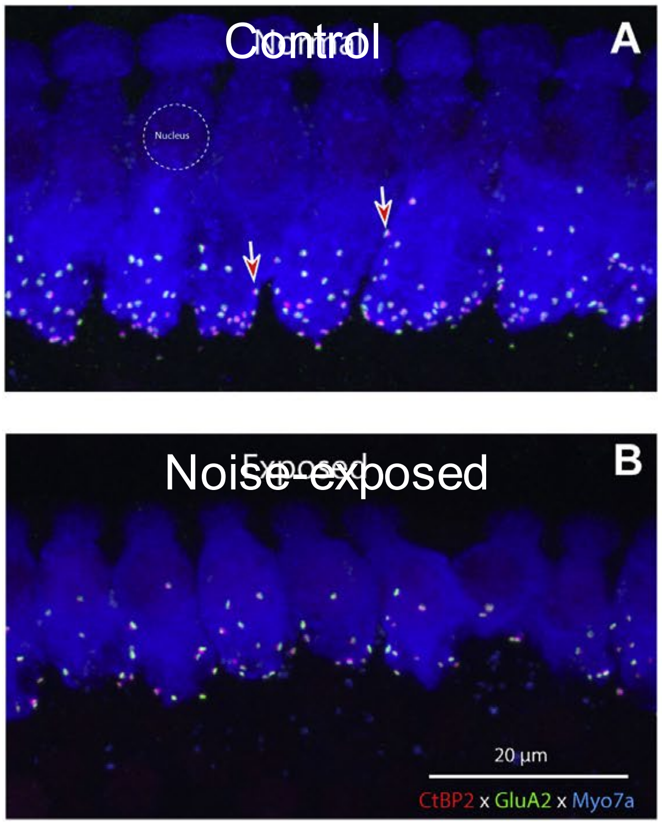
- Cochlear Damage from blast overpressurization (“Hidden Hearing Loss”)

- Hyper-excitability and increased neural noise in the auditory brainstem and cortex

- Loss of temporal precision in neural encoding

"HIDDEN HEARING LOSS"

- Noise exposure, including blast over pressurization, can lead to a significant amount of cochlear damage before hearing loss occurs



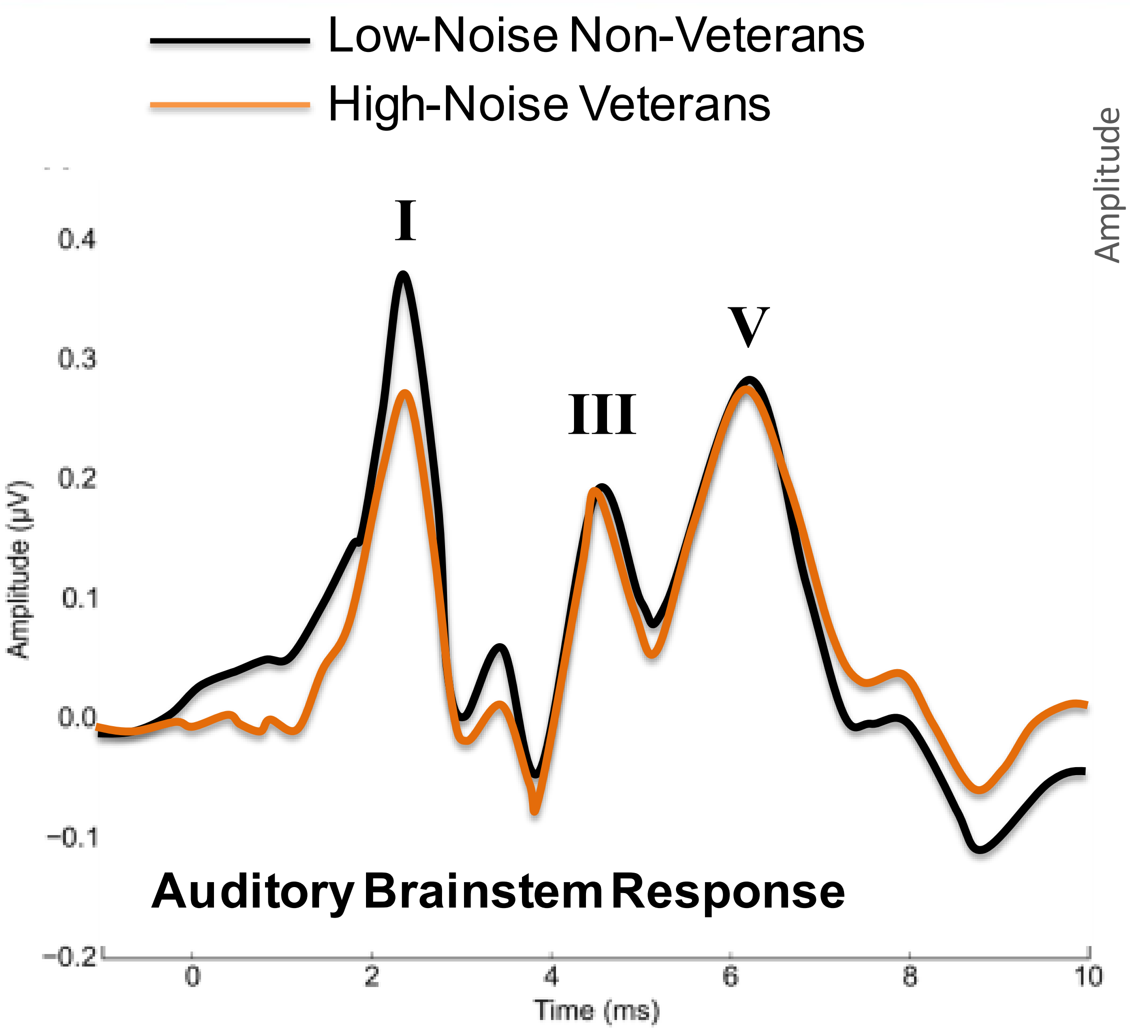
How?

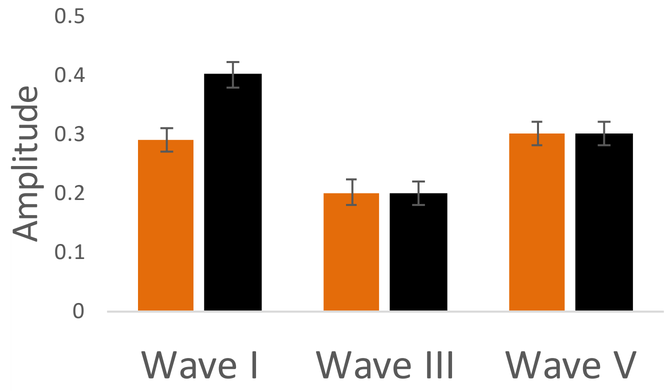
- Animal models reveal that noise is more damaging for auditory nerve fibers that code for higher-level sounds than to those that code for lower-level sounds

- Does not occur immediately
  - Synaptic loss worsens over time

Liberman, M. C., & Kujawa, S. G. (2017). Cochlear synaptopathy in acquired sensorineural hearing loss: Manifestations and mechanisms. *Hearing research*, *349*, 138-147.

"HIDDEN" HEARING LOSS: EVIDENCE IN VETERANS





- **Wave I:** Decreased input from the auditory periphery to the brainstem in noise-exposed Veterans
- **Waves III & V:** Increased central "gain", or compensation for reduced input
- Associated with increased rates of **tinnitus**

Adapted from Bramhall, et al. (2019). The search for noise-induced cochlear synaptopathy in humans: Mission impossible?. *Hearing research*, *377*, 88-103.

AUDITORY CHANGES FOLLOWING BLAST EXPOSURE

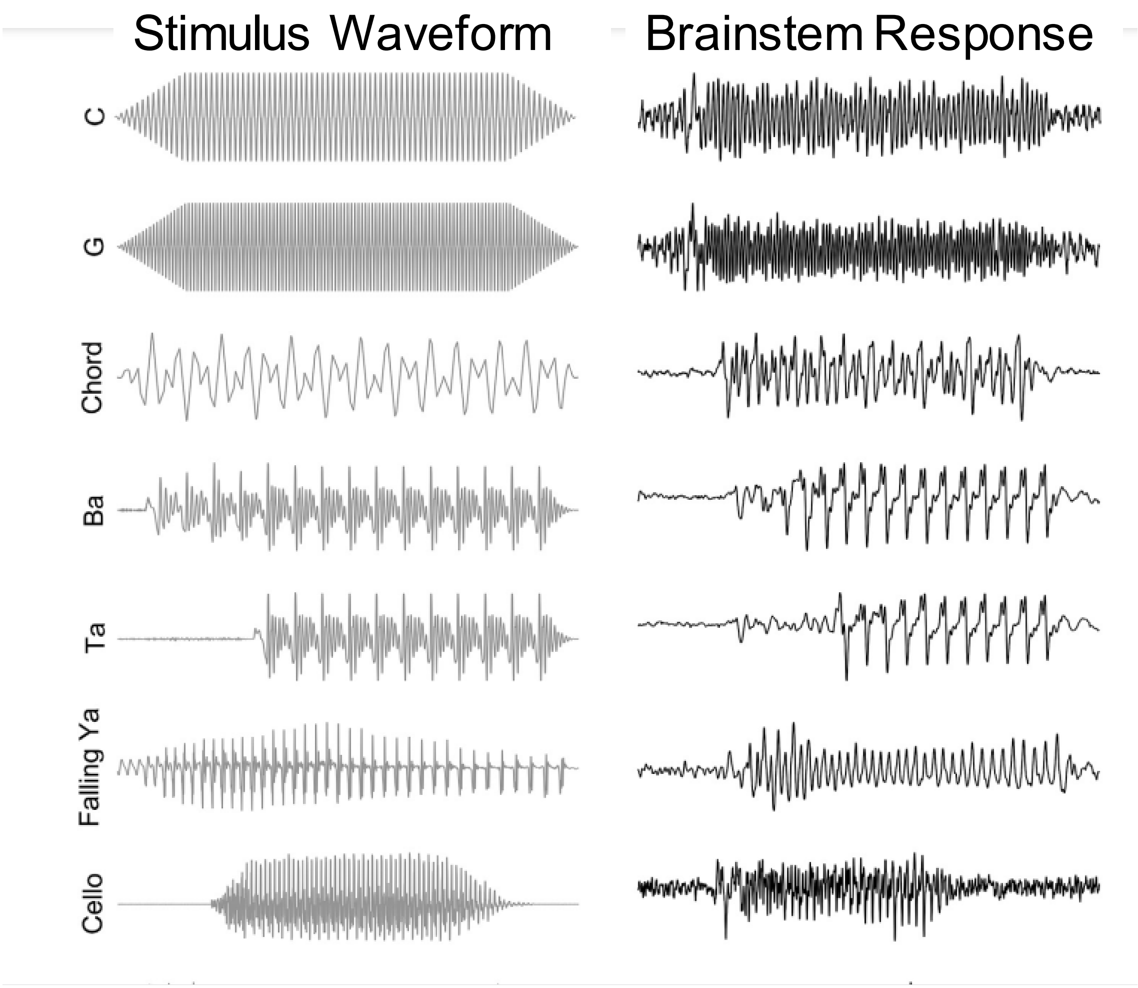
- **Cochlear Damage from blast overpressurization ("Hidden Hearing Loss")**

- **Hyper-excitability** and increased neural noise in the auditory brainstem and cortex

- Loss of temporal precision in neural encoding

THE FREQUENCY FOLLOWING RESPONSE (FFR)

- Response of brainstem neurons to both transient and periodic components of sound
- An objective measure of how well the auditory system is encoding the timing and frequency information of speech and other sounds

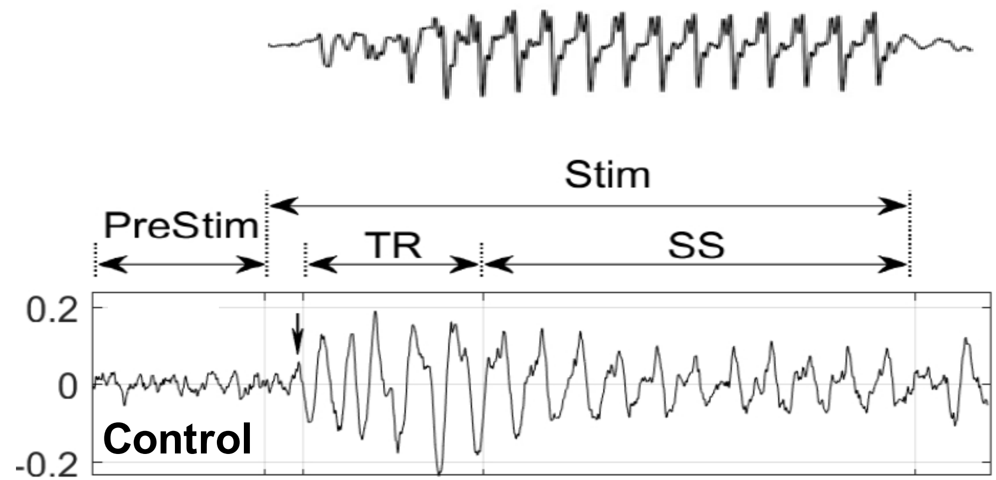


Krizman J, Kraus N (2019) Analyzing the FFR: A tutorial for decoding the richness of auditory function. *Hearing Research*. 382: 107779

FFR IN BLAST-EXPOSED VETERANS: WALTER REED STUDY, PHASE II

- FFR in response to /da/:
  - **Control**: 26 active SMs, n
    blast exposure or auditor,
    difficulties

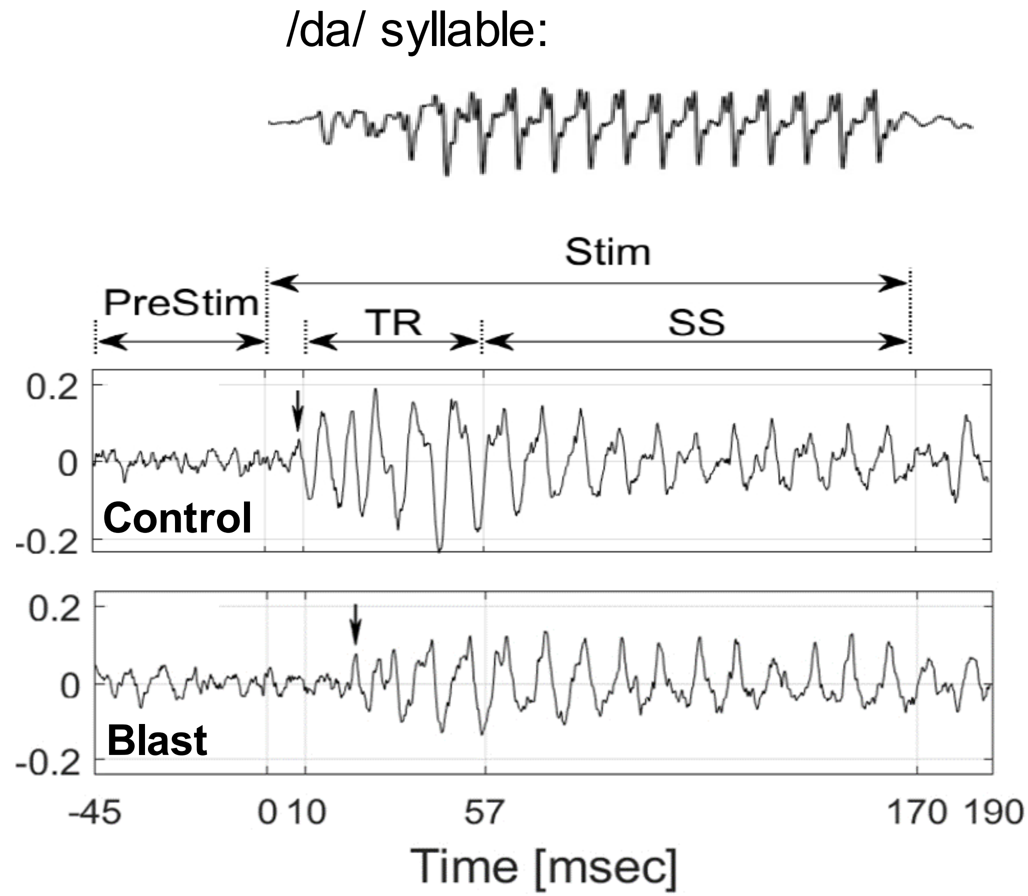
/da/ syllable:



Grant et al. (2022) Functional hearing difficulties in blast-exposed service members with normal to near-normal hearing thresholds, Poster P64, SPIN conference

FFR IN BLAST-EXPOSED VETERANS: WALTER REED STUDY, PHASE II

- FFR in response to /da/:
  - **Control**: 26 active SMs, no blast exposure or auditory difficulties
  - **Blast:** 20 Blast-exposed SMs with auditory difficulties
- Results:
  - Delayed neural response
  - Poorer neural signal-to-noise ratio
    - Noisy pre-stim baseline
  - Poorer encoding of pitch information



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- Cochlear Damage from blast overpressurization ("Hidden Hearing Loss")
- **Hyper-excitability and increased neural noise in the auditory brainstem** and cortex
- **Loss of temporal precision in neural encoding**

SUMMARY

Auditory difficulties after blast exposure:

- Are prevalent
  - Approximately 1/3 of blast-exposed SMs at risk
- Are often chronic, and may worsen over time
- May stem from factors such as:
  - Cochlear damage (Hidden Hearing Loss)
  - Hyperactivity and increased “noise” in the central auditory pathway
  - Diminished neural temporal precision

HOW YOU CAN HELP: JUST ASK!

Editorial

Concussion Management Guidelines Neglect Auditory Symptoms

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(*Clin J Sport Med* 2022;32:82–85)

TABLE 1. Common Auditory Symptoms Associated With Concussion Defined and Suggested Screening Questions

Auditory Symptoms	Definition	Screening Question
Tinnitus	Perception of sound in the absence of an external [acoustic] source.	Do you experience ringing in the ears (tinnitus) that lasts for at least 5 min?
Noise sensitivity	General intolerance to everyday sounds that encompasses a range of psychological attributes that contribute to the degree an individual is reactive to noise.	Do you have a problem tolerating sounds because they often seem too loud or bother you for other reasons?
Hearing difficulty	Trouble understanding speech or other sounds in quiet or noisy environments.	Do you have any difficulties understanding speech or other sounds? Do you feel like you have more difficulties hearing in noise compared with others?

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